

Generative Design in Architecture

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ABSTRACT

Generative design is a design method that uses algorithms and artificial intelligence (AI) to generate multiple design solutions based on specific requirements and constraints. It is the process of inputting design goals, materials, cost constraints, and other data points into software that evaluates all possible solutions. It is an iterative design process used in architecture and manufacturing. The power of this approach lies in its ability to create countless alternatives, surpassing the capabilities of the human mind. Generative design in architecture is a process that uses algorithms to generate design options based on user-defined criteria. Architects have been using digital documents for decades, from CAD drawings to spreadsheets. Generative design has ushered in a new era of architectural innovation, empowering designers to envision and construct buildings that were once considered beyond the realm of imagination. This paper examines the various uses of generative design in architecture.

KEYWORDS: *generative design, architecture, architecture industry*

INTRODUCTION

Innovations in technology have continually pushed the boundaries of what is achievable in the realm of architecture. From building information modelling (BIM) to augmented reality and the Internet of things (IoT), it is no secret that technology has transformed the way architects work and revolutionized the industry. In today's rapidly evolving architectural landscape, the fusion of technology and creativity has ushered in a new era of design possibilities. At the forefront of this revolution are building information modeling (BIM) and generative design. BIM encompasses a digital representation of physical and functional characteristics of facilities. Generative design is a design exploration process that utilizes algorithms to generate and evaluate numerous design alternatives based on specified goals and constraints, allowing architects to discover innovative solutions that may not be immediately apparent through conventional design methods. While BIM focuses on creating a digital representation of a building's physical and functional properties, generative design explores and evaluates design alternatives based on predefined criteria. BIM and generative design complement each other in the design process. BIM

provides the data infrastructure for generative design, enabling seamless integration and collaboration between the two approaches [1].

Generative design is a new innovation shaping the architectural industry. It is a strategy where the architect or user inputs data into their chosen software. Figure 1 shows an architect at work [2]. Generative design can enhance the existing design process and to make it more efficient and effective for architects and all those involved. Generative design in architecture is a method that uses algorithms and artificial intelligence to analyze, explore, and generate a series of design possibilities.

WHAT IS GENERATIVE DESIGN?

For decades, traditional design methods have been plagued by repetition and rigidity. Designers spend weeks or months developing, testing, adjusting, and refining designs, with no guarantee of optimal results. Generative design has emerged as a revolutionary solution, utilizing artificial intelligence and advanced algorithms to automate and optimize the design process. It is an iterative design process that uses software to generate outputs that fulfill a set of

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constraints iteratively adjusted by a designer. This process often involves multiple iterations until the product meets the specified technical parameters [3]. It uses software to generate outputs that fulfill a set of constraints iteratively adjusted by a designer. Examples of software that provide an option for generative design are Autodesk Revit, Infurnia, Creo, and Rhino. For example, Figure 2 shows the generative design by Autodesk [4]. These software utilize AI and machine learning algorithms to learn from each iteration and continually improve the output. One may regard the software as an assistant that helps with creating, testing, and evaluating options. They have emerged as a game-changer for professionals looking to advance their careers.

Generative design is a new design method that overcomes the limitations of traditional design. Using algorithms and artificial intelligence, generative design software automatically generates thousands of different design solutions. Figure 3 shows the traditional component design as an iterative process [3], while Figure 4 shows the generative design [3]. The iterative process provided by computer software enables the trial-and-error approach in design, and involves architects interfering with the optimisation process. Generative design is not just about creating a multitude of options. It is about refining and optimizing these options to reach the most effective solution that best meets the defined parameters and constraints.

Artificial intelligence (AI) and machine learning (ML) are at the core of the generative design process. They play a crucial role in generative design by automating the design process. AI can quickly generate and evaluate different design options. Generative design integrates AI into the design process by using metaheuristic search algorithms to discover novel and high-performing results within a given design system.

The system works by iterating through various options and optimizing them to find the best design. The designer inputs their requirements into the generative design tool. Then, the tool will generate different designs according to the designer's requirements and local regulations. As shown in Figure 5, the process has three overall stages [4]. They are:

1. *Pre-Generative Design*: The preliminary stage is called pre-generative design (Pre-GD). At this stage, you have to define goals, identify important parameters that are important in achieving them and specify constraints. This data might include design goals, time or cost constraints, materials and other relevant information. These constitute a set of data

that are used to kick start the main generative design process. The more precise data gathered and input into the generative process the more efficient and fine-tuned results will be achieved.

2. *Generative Design*: The second stage or the main stage is where computer algorithms come into play. Provided with the data, it starts a cyclical process of generative design (GD), which can be divided into three stages itself.

- *Generate*: From a seed given by the human operator and using the defined parameters, the computer algorithm creates a variety of designs.
- *Evaluate*: The computer analyzes the results and calculates their compatibility with the requirements defined at the preliminary stage.
- *Evolve*: The algorithm decides the direction of a new cycle of design, based on the most compatible out of the evaluated options, using that option as a new seed to begin the whole process all over again.

This process repeats the cycle several times before moving on to the next stage.

3. *Post-Generative Design*: The third stage or the finalizing stage is called post-generative design (Post-GD). At this stage, the designer and stakeholders can explore and choose between a final set of proposed designs produced by the process, and then the architects and professionals can develop and manually refine the chosen option further and ensure constraints and requirements are met. It is composed of two key steps: selection and refinement.

GENERATIVE DESIGN IN ARCHITECTURE

Architectural design is an iterative process. It requires multiple trials and errors to arrive at the best possible solution. Traditionally, sketchbooks, pencils, pens, and markers have been architects' best friends throughout their design journey, from ideation to realization. This is typically illustrated in Figure 6, where architects use traditional tools [5]. These conventional tools are time-consuming and do not offer enough agility to experiment with design. The use of computers has set the stage for a digital revolution in architecture. Next-generation design technology, such as generative design, is taking the architecture, engineering, and construction (AEC) industry by storm.

Generative design in architecture is an iterative design process that enables architects to explore a wider solution space with more possibility and creativity. It is a new method of design that enables you to discover unexpected novel designs and navigate trade-offs between high-performing designs,

sketch constraints, and goals rather than form and co-design between human and computer. It empowers architects to explore unconventional design solutions, optimize building performance, and respond to complex design challenges with agility and creativity. Compared with traditional top-down design approach, generative design can address design problems efficiently, by using a bottom-up paradigm that uses parametric defined rules to generate complex solutions.

Generative design is disruptive; it changes the role of architects and the entire design methodology. The architect's role shifts from creating designs to setting the parameters and constraints for the generative model. The architect will use computers not just to describe buildings, but cocreate them. Such methodology introduces new ways to think, make, and produce architecture, streamlining collaboration efforts between designers and clients while unlocking the creative power of artificial intelligence for designers and engineers.

APPLICATIONS OF GENERATIVE DESIGN IN ARCHITECTURE

Generative design is not only a powerful design tool but also offers diverse applications in numerous fields such as aerospace, aviation, automotive industry, manufacturing, construction, and architecture. Within architecture and construction, generative design helps optimize building structures to ensure sustainability and cost-effectiveness. By leveraging advanced computational tools and techniques, architects can push the boundaries of architectural expression and create iconic structures that redefine the urban landscape. Generative design allows architects and builders to use data to create new and innovative solutions to common building roadblocks. Common areas of applications include the following:

- *Building Design:* Buildings and bridges designed using this method often possess complex structures while maintaining durability and efficient material utilization. Generative design tools like Autodesk's Project Refinery have been used to optimize building designs for sustainability, resulting in reduced environmental impact and resource consumption. By integrating environmental performance metrics into the design process, architects can create buildings that are not only aesthetically compelling but also environmentally responsible and resilient. Generative design allows architects and builders to use data to create new and innovative solutions to common building roadblocks. Figure 7 shows a typical building design [3].

- *Space Design:* In architecture, drawing is a technical and artistic expression that involves creating visual representations using various analog instruments. While drawing remains relevant and current in practice today, efforts have been made to carry out architectural tasks and studies more efficiently. The emergence of computational tools, such as computer-aided drafting (CAD), has revolutionized the workflow by leveraging the advantages offered by computers. Architects can now play a more direct and creative role in the design process, reducing their reliance on time-consuming drawing and repetitive tasks. A typical space design is shown in Figure 8 [5].

- *Additive Manufacturing:* Combining generative design technology with advancements in additive manufacturing (or 3D printing) has the potential to fundamentally change how we think about architecture. Instead of designing building envelopes made up of separate layers for heating, ventilation, passive solar gain, and other necessities, these needs could be accounted for within a single, complex "skin" that possesses qualities that mimic biological organisms. The possibilities are startling.

- *Vertical Cities:* As one of the tallest skyscrapers in the world, the Shanghai Tower in China showcases the immense possibilities of generative design in creating sustainable and resilient vertical cities. The tower used generative design algorithms to optimize the building's shape for wind resistance and energy efficiency. The tower's iconic twisting form not only enhances its visual appeal but also gives the building structural stability. The tower is shown in Figure 9 [6].

BENEFITS

Despite its growing popularity in architecture, generative design has its pros and cons. Generative design offers many advantages over traditional design methods. This technology enables the creation of thousands of design solutions in a short period, saving costs and expanding creative possibilities far beyond traditional methods. Generative design not only optimizes design and manufacturing methods but also saves production costs and enhances product value. Generative design helps designers reduce the time needed to create a product. Other benefits include the following [2,3]:

- *Creative Designs:* Generative design is a creative process. It can create products with geometries and structures that even professional designers cannot imagine. This helps expand the boundaries of creativity and explore new possibilities in

product design. As the design options produced by generative design tools are way beyond what the human mind can envisage, it helps one overcome creative barriers.

- *Speed:* Generative design also speeds up the design process. It allows the designer to work faster, make better-informed design decisions and provide them with data to justify specific design choices. What would take a human architect weeks to achieve can be done in a matter of hours or even minutes with AI. This efficiency does save time and leads to a better end product.
- *Efficiency:* Design algorithms enable architects to explore a vast design space efficiently, considering multiple factors such as performance, aesthetics, and user preferences simultaneously. The designs are created based on specific manufacturing constraints and requirements, ensuring feasibility and efficiency in production.
- *Reduced Costs:* By optimizing material usage and manufacturing, generative design helps reduce production costs. This not only reduces waste but also increases the economic value of the final product. Designs produced by generative modeling do not require additional simulation or testing. The designs adhere to safety norms and are ready for execution because simulation is built into it as a feature. Thus, an advantage of generative design is that it leads to lower costs and frees up budget for other processes.
- *Reduced Weight:* One of the major advantages of generative design is its ability to create lighter designs while maintaining high strength and performance. This is particularly important in industries such as aerospace and automotive, where reducing product weight can lead to fuel savings and improved overall performance.
- *Design Automation:* Design must be done by humans, and computers are there to automate tasks and save time for us. Generative design accelerates the design process by automating repetitive tasks and exploring a vast array of design alternatives. By defining design objectives and constraints, architects can leverage generative design algorithms to generate and evaluate thousands of design options quickly, facilitating informed decision-making and design optimization. It is not surprising that generative design, which is a step ahead of parametric modeling, is capable of automated adjustments.
- *Optimizing Performance:* Generative design enables architects to optimize building performance by evaluating design alternatives against performance criteria such as energy efficiency, structural integrity, and occupant comfort.
- *Customization:* Generative design facilitates the creation of customized and personalized architectural solutions that respond to specific site conditions, user needs, and project requirements. By incorporating user preferences and constraints into the design process, architects can create spaces that are tailored to the unique needs and aspirations of their clients.
- *Countless Choices:* One major advantage of using generative design as a design tool is that it can generate an infinite set of possible design solutions. A team can literally try hundreds of options to find the best solution. Backed by the storage capacity of cloud, an advantage of generative design is that the process produces hundreds of design iterations despite specified constraints. This is well beyond what an architect or designer can manually create. The advantage of generative design is that it helps create multiple creative options within a short period- a task which is humanly impossible.
- *Free Up Time:* An advantage of generative design is that it helps architects skip the need of coming up with designs and manually navigating the design options. It frees up their time so that they can focus on more human and practical engagements. It allows them to take up a more strategic role.
- *Human Factors:* By considering human factors such as ergonomics, circulation, and comfort, architects can design spaces that enhance the quality of life for occupants and foster a sense of connection and belonging.
- *Sustainable Design:* Generative design in sustainable design is an effective approach addressing energy efficiency and climate change at the early design stage. It integrates environmental principles with algorithms, enabling exploration of countless design alternatives to enhance energy performance, reduce carbon footprints, and minimize waste. This not only minimizes waste and costs but also improves efficiency, making designs sustainable.
- *Improved Collaboration:* With cloud computing capabilities, generative design architecture software enables better collaboration between team members, stakeholders, and even clients to have an integrated, streamlined design process in place. While it is great that architects and other members of the team can view the designs on a

shared platform, without a clear and transparent framework for decision-making and feedback, this can lead to confusion or frustration.

CHALLENGES

Challenges such as data interoperability, computational complexity, and skill gaps pose obstacles to widespread adoption of generative design in practice. Addressing these challenges requires investment in training, infrastructure, and collaboration across disciplines to ensure successful implementation and integration into existing workflows. While embraced by a large part of the AEC community, generative design and its reliance on artificial intelligence has raised some concerns. Balancing multiple design objectives while limiting computational costs adds further challenges for designers. Other challenges include the following [1,2,7]:

- *Human Creativity:* While generative design offers unprecedented opportunities for automation, it is essential to maintain a balance between computational efficiency and human intuition to ensure the integrity. Architects must resist the temptation to rely solely on algorithmic solutions and instead embrace technology as a tool to augment and enhance human creativity and ingenuity.
- *Making Humans Redundant:* Architects wonder if the machine learning-enabled software feature would replace the need for designers and architects in the future. Generative design proponents believe such fears are unfounded. They believe that architects need to expand their skill sets. Generative design is just another tool in the toolbox. After all, there is a lot more to the architectural profession than constraint-based design.
- *Emerging Technologies:* Advancements in emerging technologies such as artificial intelligence, machine learning, and cloud computing are poised to further enhance the capabilities and accessibility of generative design tools. These technologies will enable architects to tackle increasingly complex design challenges and explore new frontiers in architectural expression and innovation.
- *Ethical Issues:* Generative design relies on AI, automation, and the use of potentially sensitive data. This can raise questions about ownership, responsibility, and liability. There could also be issues around privacy, security, and consent of the data sources.
- *Algorithm Bias:* Concerns regarding the loss of human agency and the potential for algorithmic bias necessitate careful consideration and ethical oversight in the development and implementation of generative design tools. Architects must remain vigilant and critical of the outputs generated by algorithms, recognizing their limitations and biases and actively engaging in the design process to ensure that human values and priorities are upheld.
- *Shortlisting Options:* Interestingly, a disadvantage of generative design is that it throws up too many options. There are software designed to filter options based on cost or other parameters. But there many software that do not provide an advanced filtering option. Architects seldom have the time and money to explore all the possibilities and have to settle on a design at some point. They do not have the time or interest to tediously filtering out designs. Thus, sometimes, it can get a little too overwhelming.
- *Manual Intervention:* Though largely automated, a disadvantage of generative design is that it does require architects to be capable of leveraging machine learning and AI to their advantage. Otherwise, the resulting designs may not stand up to the high expectations we have, out of generative design.
- *Quality of Data:* As generative design tools rely on data from a real-world setting, this data needs to be as accurate as possible. Inaccurate, outdated or incorrect information can lead to flawed designs that do not meet the project requirements.
- *Skills Gaps:* Generative design tools are complex and sophisticated and architects can find this daunting if they have not used them before. This means that many would need to be retrained, otherwise the industry could face an ongoing skills shortage. Generative design tools operate on sophisticated algorithms, making them technically complex and potentially daunting for professionals unfamiliar with computational tools. Architects need to invest their time and energy in learning and upskilling in the realms of coding and generative design tools.
- *Software Compatibility:* It can be tough to find the right generative design software that is compatible with existing systems and workflows, as this often requires specialised platforms. As such, architects will need to evaluate the compatibility of the software to make sure it will support their design goals.

CONCLUSION

Generative design is transforming the architecture industry and built environment. It has become a paradigm shift in architecture. It enables architects to create more efficient, innovative, and personalized designs in less time. It is revolutionizing the way architects approach creativity, efficiency, and problem-solving. Although generative design is still a relatively new design technology, it is slowly making its way into the world of architecture.

Generative design is making a name in the world of contemporary architecture. In order to take generative design to the next level in the AEC, the industry must first upgrade its technology and data literacy to understand the outcomes that result from using these powerful tools. The integration of generative design into architectural curricula and professional practice is reshaping how architects learn, design, and collaborate. More information on the integration of generative design into the architecture industry is available from the books in [8-11].

REFERENCES

- [1] T. Kaarwan, "BIM and generative design: Exploring algorithmic design approaches" <https://www.kaarwan.com/blog/architecture/BIM-and-generative-design?id=396>
- [2] "Advantages & disadvantages of generative design," August 2020, <https://www.infurnia.com/blog/generative-design-pros-cons>
- [3] T. Chu, "Benefits of generative design in design and manufacturing," <https://vinnotek.com/blogs/danh-muc-blog-tieng-anh/benefits-of-generative-design-in-design-and-manufacturing#:~:text=Generative%20design%20not%20only%20optimizes,that%20traditional%20design%20cannot%20achieve.>
- [4] "Generative design for architectural space planning," <https://www.autodesk.com/autodesk-university/article/Generative-Design-Architectural-Space-Planning>
- [5] E. Tovar, "Generative space design: Exploring 8 transformative tools in architecture," June 2023, <https://www.archdaily.com/1001757/generative-space-design-exploring-8-transformative-tools-in-architecture>
- [6] P. Sharma, "How generative design is shaping the future of architecture?" August 2023, <https://parametric-architecture.com/how-generative-design-is-shaping-the-future-of-architecture/?srltid=AfmBOodkHhwQw8rVG0mB8SY7cq8qGmQwIilrKL7qRh7NoHodH-47iBa>
- [7] "The architect's guide to generative design," July 2024, https://www.google.com/search?q=The+architect%E2%80%99s+guide+to+generative+design%2C+15+July%2C+2024%2C+p.116&rlz=1C1UEAD_enUS1082US1082&oq=The+architect%E2%80%99s+guide+to+generative+design%2C+15+July%2C+2024%2C+p.116&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRiPAjIHCAIQIRiPAjIBCDMyMDBqMGo3qAIAAsIA&sourceid=chrome&ie=UTF-8
- [8] E. Lanzara, *Generative Design Strategies for Customizable Prototypes: Academic Research and Entrepreneurial Education*. IGI Global, 2021.
- [9] A. Agkathidis, *Generative Design: Form-finding Techniques in Architecture (Form + Technique)*. Laurence King Publishing, 2016.
- [10] C. Cogdell, *Toward a Living Architecture? Complexism and Biology in Generative Design*. University of Minnesota Press, 2019.
- [11] X. Marsault, *Eco-generative Design for Early Stages of Architecture*. Wiley-ISTE, 2017.

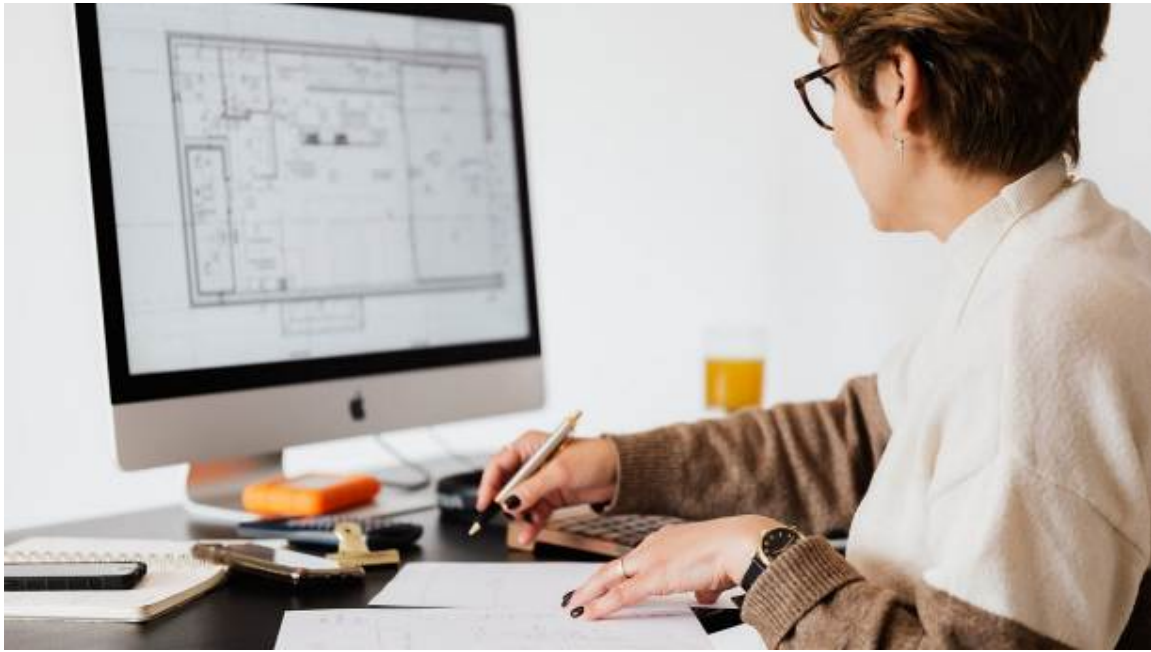


Figure 1 An architect at work [2].



Figure 2 Generative design by Autodesk [4].

TRADITIONAL COMPONENT DESIGN PROCESS

Characterized by many evaluation iterations

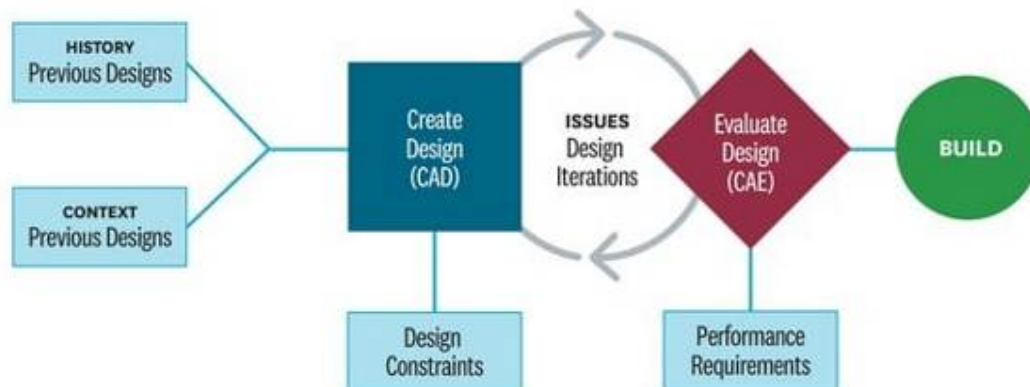


Figure 3 Traditional component design as an iterative process [3]

GENERATIVE DESIGN PROCESS

Optimization should directly create feasible and buildable designs

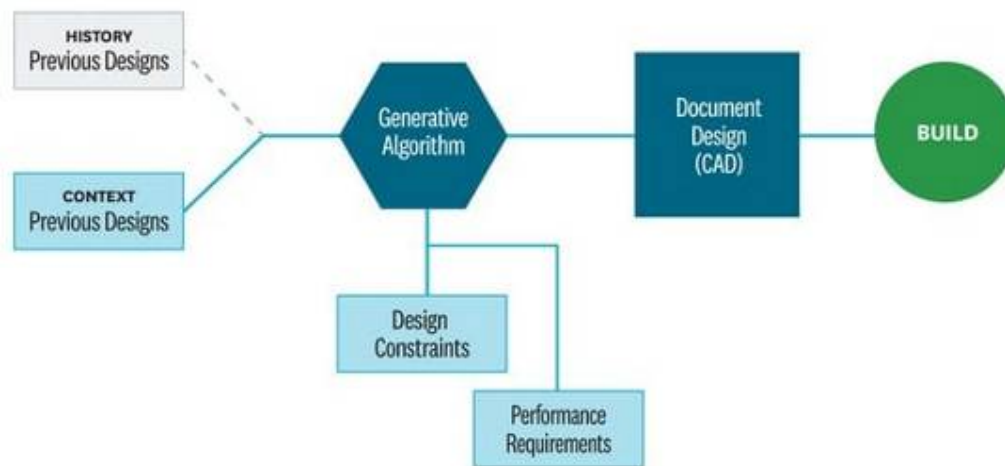


Figure 4 Generative design [3].

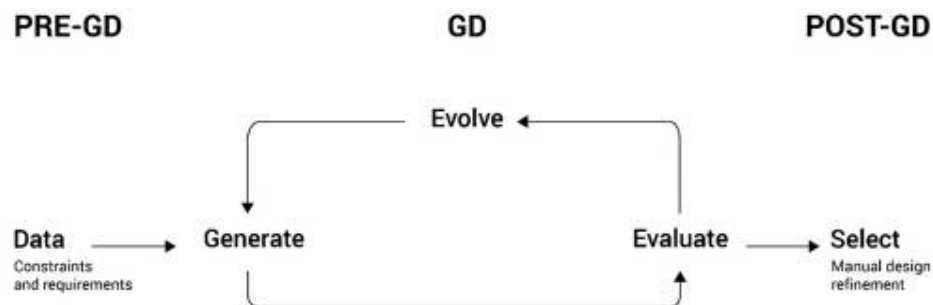


Figure 5 Generative design process has three overall stages [4].



Figure 6 Traditional architects [5].



Figure 7 A typical building design [3].

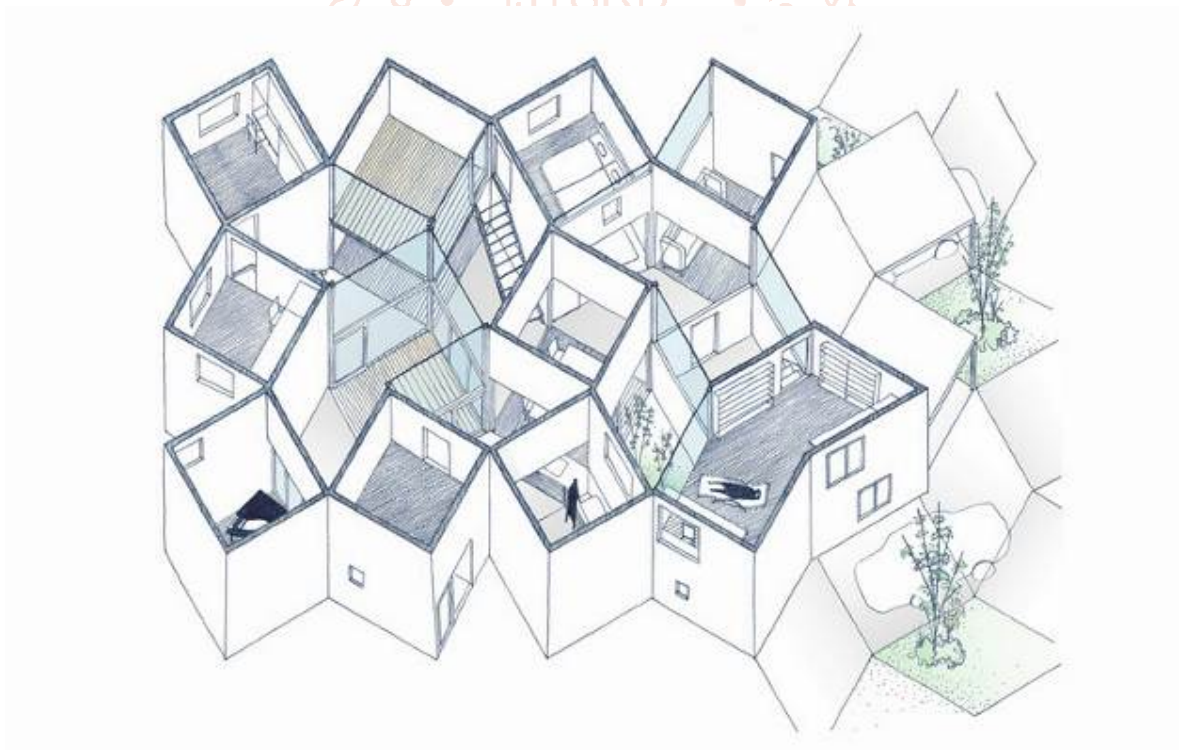


Figure 8 A typical space design [5].



Figure 9 The Shanghai Tower in China [6].